

d–Au and p–p collisions at RHIC and the multichain Monte Carlo DPMJET-III *

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In this paper we compare systematically the two-component Dual Parton Model (DPM) event generator DPMJET-III to d–Au and p–p data from RHIC. In this process we are able to improve the model. The need for fusion of chains and a recalibration of the model to obtain collision scaling in h–A and d–A collisions was found already in previous comparisons. Here, comparing to transverse momentum distributions of identified charged hadrons we find also the need to modify the transverse momentum distributions in the decay of hadronic strings, the basic building blocks of the model on soft hadronic collisions.

1. Introduction

Hadronic collisions at high energies involve the production of particles with low transverse momenta, the so-called *soft* multiparticle production. The theoretical tools available at present are not sufficient to understand this feature from QCD alone and phenomenological models are typically applied in addition to perturbative QCD. The Dual Parton Model (DPM) [1] is such a phenomenological model and its fundamental ideas are presently the basis of many of the Monte Carlo implementations of soft interactions.

The soft component of the Dual Parton Model contains some features to be determined from multi-particle production data. This is so for the fragmentation of chains. But it also concerns the general event structure. Already in Ref. [2] we have used data from RHIC to tune some of the properties of the soft particle production model contained in DPMJET-III. This process will be continued here using mainly RHIC data on d–Au and p–p collisions.

The DPMJET-III code system [3,4] is a Monte Carlo event generator implementing Gribov–

Glauber theory for collisions involving nuclei, for all elementary collisions it uses the DPM and (LO) perturbative QCD as implemented in PHOJET1.12 [5,6].

DPMJET-III is unique in its wide range of application simulating hadron-hadron, hadron-nucleus, nucleus-nucleus, photon-hadron, photon-photon and photon-nucleus interactions from a few GeV up to cosmic ray energies.

The properties of DPMJET-III were recently summarized in Ref. [2]. For a more detailed description of DPMJET-III we refer to this paper and the literature quoted there.

2. Comparing the original Dpmjet-III with RHIC data

In Ref. [2] we found an excellent agreement of DPMJET-III up to transverse momenta of about $p_{\perp} = 10$ GeV/c to π^0 transverse momentum distribution in p–p collisions at $\sqrt{s} = 200$ GeV from PHENIX [7].

In the same paper, comparing DPMJET-III with multiplicity data from RHIC in central Au–Au collisions we found a problem which let us introduce percolation and chain fusion into DP-

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MJET-III. The groups at Lisboa [8,9,10] and Santiago de Compostela [11] were the first to point out, that the multiplicities measured at RHIC are significantly lower than predicted by conventional multi-string models. A new process is needed to lower the multiplicity in situations with a very high density of produced hadrons like in central nucleus–nucleus collisions. The percolation process, which leads with increasing density to more and more fusion of strings, is one such mechanism [12,13].

3. Pseudorapidity distributions in d-Au and p–p collisions and DPMJET-III

Pseudorapidity distribution of charged hadrons produced in minimum bias $\sqrt{s} = 200$ GeV d–Au collisions were measured at RHIC by the PHOBOS–Collaboration[14] and by the BRAHMS Collaboration[15]. In Fig.1 we compare the preliminary PHOBOS data and the preliminary BRAHMS data to DPMJET-III calculations. Using DPMJET-III without fusion of chains we find the DPMJET distribution above the experimental data outside the systematic errors. Using DPMJET-III with fusion of chains we find the DPMJET distribution within the systematic errors of both experiments.

In [16] the PHOBOS Collaboration also presents preliminary data on the pseudorapidity distribution of charged hadrons in p–p collisions at $\sqrt{s} = 200$ GeV. In Fig.1 we compare DPMJET-III also with these data and find an excellent agreement.

Pseudorapidity distributions of charged hadrons in d–Au collisions with specified centralities were given by the BRAHMS–Collaboration[15] and by the PHOBOS–Collaboration[17]. In Fig.2 we compare the preliminary PHOBOS–data with results from DPMJET. In the most central collisions we find an excellent agreement. In DPMJET-III we know the impact parameter of the collision and we determine the centrality according to the impact parameter distribution. This might give results slightly different from the PHOBOS centrality determination, also the the number of participants determined by PHOBOS and obtained from DPMJET-III differs for centralities between 20 and 80 % , see Table 1.

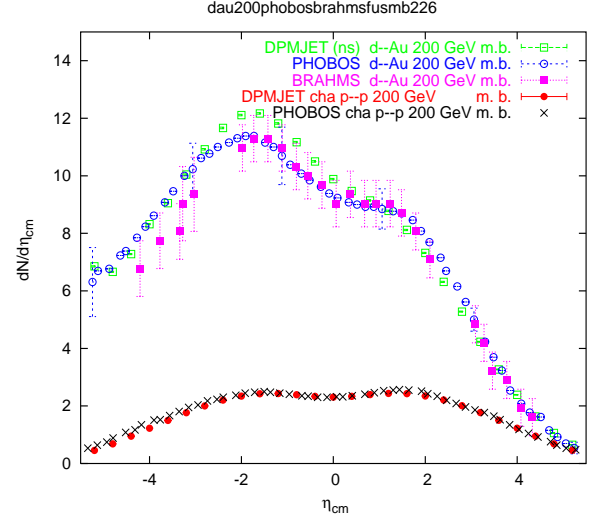


Figure 1. Pseudorapidity distribution of charged hadrons produced in minimum bias $\sqrt{s} = 200$ GeV d–Au and p–p collisions. The results of DPMJET with fusion of chains are compared to preliminary experimental data from the BRAHMS–Collaboration[15] and the PHOBOS–Collaboration[14,16]. At some pseudorapidity values the systematic PHOBOS–errors as estimated by the experimental collaboration are given.

Table 1. Numbers of participants in d–Au collisions with different centralities. PHOBOS numbers taken from [17]

Centrality %	source	N_{part}	$N_{part}(\text{Au})$	$N_{part}(\text{d})$
0–20 %	PHOBOS	15.5	13.5	2.0
	DPMJET	15.4	13.5	2.0
20–40 %	PHOBOS	10.8	8.9	1.9
	DPMJET	11.7	9.8	1.94
40–60 %	PHOBOS	7.2	5.4	1.7
	DPMJET	7.8	6.0	1.76
60–80 %	PHOBOS	4.2	2.9	1.4
	DPMJET	4.7	3.24	1.41
80–100 %	PHOBOS	2.7	1.6	1.1
	DPMJET	2.9	1.8	1.1

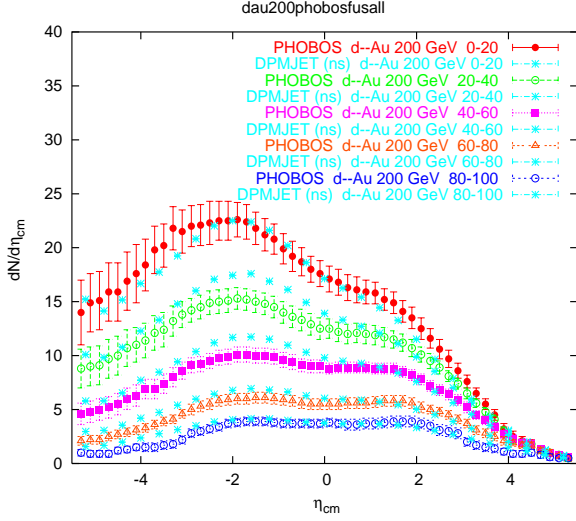


Figure 2. Pseudorapidity distribution of charged hadrons produced in non-single-diffractive (ns) $\sqrt{s} = 200$ GeV d-Au collisions with different centralities. The results of DPMJET with fusion of chains are compared to preliminary experimental data from the PHOBOS-Collaboration[17].

4. Transverse momentum and transverse energy distributions of charged hadrons in d-Au collisions and DPMJET-III

Let us repeat an important DPMJET modification introduced already in our previous paper [2]. Several RHIC experiments (see for instance [18]) found in d-Au collisions at large p_{\perp} a nearly perfect collision scaling for π^0 production. Collision scaling means $R_{AA} \approx 1.0$ where the R_{AA} ratios are defined as follows:

$$R_{AA} = \frac{\frac{d^2}{dp_{\perp} d\eta} N^{A-A}}{N_{binary}^{A-A} \cdot \frac{d^2}{dp_{\perp} d\eta} N^{N-N}} \quad (1)$$

Here N_{binary}^{A-A} is the number of binary Glauber collisions in the nucleus-nucleus collision A-A.

DPMJET-III in its original form gave for π^0 production in d+Au collisions strong deviations from collision scaling ($R_{AA} \approx 0.5$ at large p_{\perp}). The reason is understood[2]. Using a modified iteration procedure it was possible in [2] to obtain a nearly perfect collision scaling.

Having shown the collision scaling of the model in [2] we will here compare the model directly with the measured transverse momentum and transverse energy distributions. Transverse momentum distributions in mini-

mum bias d-Au collisions were measured by the PHENIX-Collaboration[19] and by the STAR-Collaboration[20]. In Fig.3 we compare the preliminary PHENIX-data for positively charged hadrons with DPMJET-III as described so far.

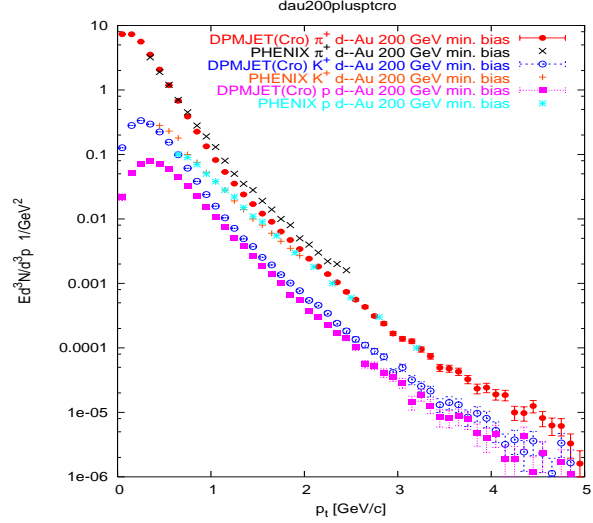


Figure 3. Transverse momentum distributions of positively charged hadrons in minimum bias d-Au collisions. Compared are the preliminary data from the PHENIX-Collaboration[19] to the results of the original DPMJET-III.

For charged Pion production we find in Fig.3 quite a good agreement between DPMJET-III and the preliminary PHENIX-data. This agreement is similar to the good agreement found already in Ref. [2] for π^0 production in p-p and d-Au collisions. However, it seems, that the DPMJET-III model fails to describe the p_{\perp} distributions of heavier hadrons like Kaons and protons. The prediction is slightly too steep. This is the first time that we are able to compare the DPMJET-III model to p_{\perp} distributions of identified hadrons like K^+ , K^- , protons and antiprotons. In the past usually only data for all charged hadrons were available. Therefore, it is not surprising to find problems.

The reason for this disagreement is the following:

DPMJET uses the PYTHIA code [21] for the fragmentation of all chains (hard, QCD based

chains as well as soft chains). PYTHIA selects in the PYPTDI function the transverse momenta of (for instance) $q - \bar{q}$ pairs (to become hadrons finally) from independent Gaussians in the $p_{\perp x}$ and $p_{\perp y}$ components of p_{\perp} . PYTHIA was extensively tested in processes with a significant hard component, for the fragmentation of hard chains this choice is reasonable, but the fragmentation of the soft component is not well determined.

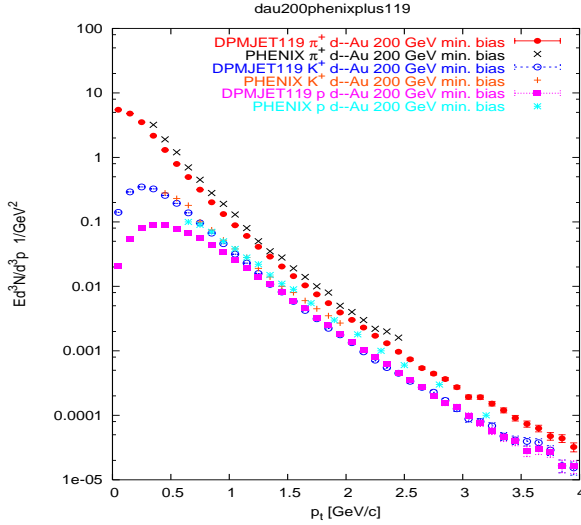


Figure 4. Transverse momentum distributions of positively charged hadrons in minimum bias d-Au collisions. Compared are the preliminary data from the PHENIX-Collaboration[19] to the results of DPMJET-III with modified transverse momentum distribution in hadronic soft chain decay as described in the paper.

Otherwise, it is known since very many years (given already in 1968 in Ref. [22], but this might even not be the first Reference) that the transverse momentum distribution for hadrons with mass m in soft hadronic collisions is well described by an exponential in the transverse energy

$$\exp(-m_{\perp}/T), \quad m_{\perp} = \sqrt{p_{\perp}^2 + m^2}. \quad (2)$$

We here chose a similar parametrization and replace the Gaussian in PYPTDI of PYTHIA by the distribution

$$\exp(-\sqrt{p_{\perp}^2 + m_x^2}/\sigma), \quad m_x = 0.33 \text{ GeV}/c. \quad (3)$$

After such a change all PYTHIA parameter which relate to the fragmentation have to be reoptimized.

With this modification we compare DPMJET-III again to the PHENIX-transverse momentum distributions [19] in Fig.4 for positively charged hadrons and in Fig.5 for negatively charged hadrons. To be definitive: we use DPMJET-III with (i) chain fusion [2], (ii) anomalous baryon stopping as described in Ref. [23], (iii) the modified iteration procedure to obtain collision scaling [2] and (iv) the changed transverse momentum distribution in soft chain decay as described above. We find in both Figures a much improved agreement to the preliminary PHENIX-data [19]. At sufficiently large p_{\perp} the p_{\perp} distributions of Pions, Kaons and baryons have the same exponential slope.

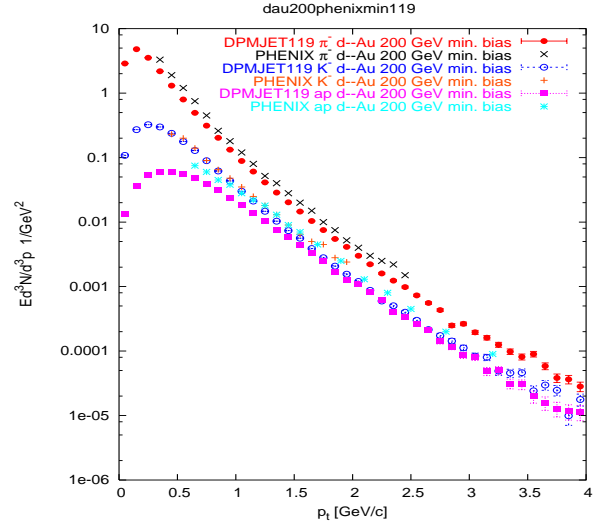


Figure 5. Transverse momentum distributions of negatively charged hadrons in minimum bias d-Au collisions. Compared are the preliminary data from the PHENIX-Collaboration[19] to the results of DPMJET-III with modified transverse momentum distribution in hadronic soft chain decay as described in the paper.

As a further check we present in Figs. 6 and 7 the comparison of the modified DPMJET-III with transverse energy distributions of identified charged hadrons as measured by the PHOBOS-Collaboration[24]. Before the modification there

were discrepancies between the Kaon and baryon distributions similar to the ones in Fig.3. The agreement in Figs. 6 and 7 is now much better.

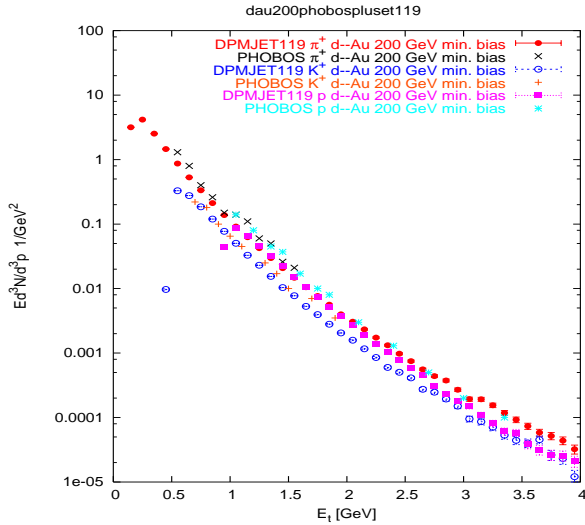


Figure 6. Transverse energy distributions of positively charged hadrons in minimum bias d-Au collisions. Compared are the preliminary data from the PHOBOS-Collaboration[24] to the results of DPMJET-III with modified transverse momentum distribution in hadronic soft chain decay as described in the paper.

Finally in Fig.8 we compare the modified DPMJET-III with the transverse momentum distribution of all charged hadrons as measured by the PHENIX-Collaboration[18]. We find a reasonable agreement.

5. Transverse momentum distributions of charged hadrons at different pseudorapidities

Transverse momentum distributions of all charged hadrons and of all negatively charged hadrons at different pseudorapidities were measured by the BRAHMS-Collaboration[25] in d-Au and p-p collisions. The interesting point in these measurements is the gradual change of the shape of the p_\perp distribution with changing pseudorapidity and the corresponding evolution of the nuclear modification factors. In Figs. 9 and 10 we compare the modified DPMJET-III as described

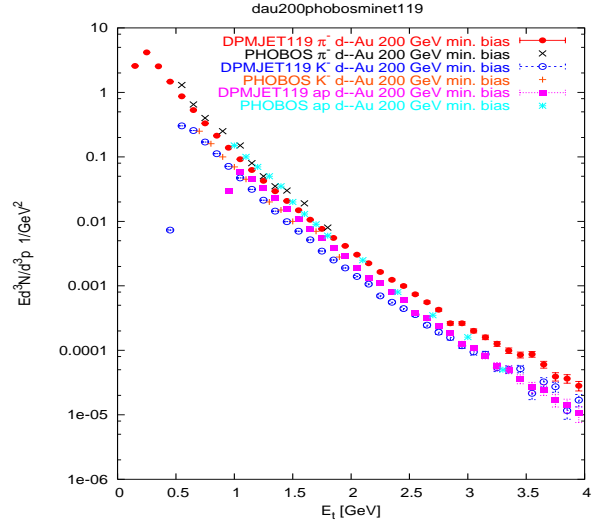


Figure 7. Transverse energy distributions of negatively charged hadrons in minimum bias d-Au collisions. Compared are the preliminary data from the PHOBOS-Collaboration[24] to the results of DPMJET-III with modified transverse momentum distribution in hadronic soft chain decay as described in the paper.

in this paper with the preliminary d-Au and p-p data of the BRAHMS-Collaboration[25] at pseudorapidities of 0, 1, 2.2 and 3.2. In the DPMJET-III calculations we are not able to simulate the quite complicated pseudorapidity acceptances as given in [25], instead we use in all cases a pseudorapidity band of width 0.2 centered at the nominal pseudorapidity. This difference might be responsible for part of the differences we find between the model and the data. There is no essential difference between the agreements for d-Au and p-p. The model follows the change of the shapes of the data with changing pseudorapidity, but the agreement is not perfect.

6. p-p collisions in DPMJET-III

We are here mainly concerned with d-Au collisions, but the changes of Dpmjet described in the last Section will also change hadron production in p-p collisions. Therefore, let us shortly discuss p-p collisions at the energy of the RHIC collider.

In Fig.1 we did already compare DPMJET-III with the preliminary data of the PHOBOS Collaboration[16] for the pseudorapidity distribution of charged hadrons in p-p collisions at $\sqrt{s} =$

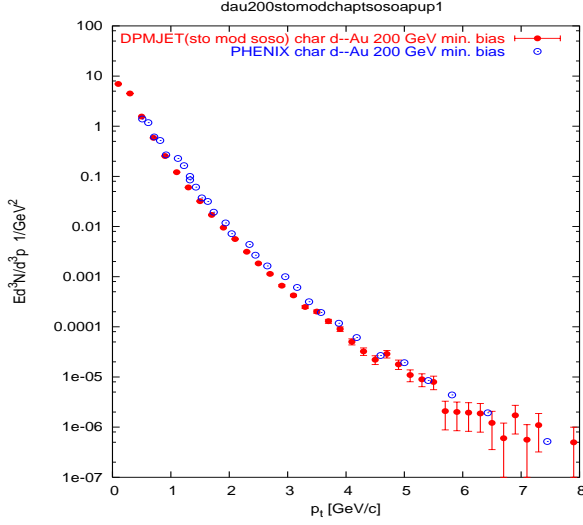


Figure 8. Transverse momentum distributions of all charged hadrons in minimum bias d-Au collisions. Compared are the preliminary data from the PHENIX-Collaboration[18] to the results of DPMJET-III with modified transverse momentum distribution in hadronic soft chain decay as described in the paper.

200 GeV. We found an excellent agreement similar to the agreement found in earlier comparisons with data from the CERN-SPS and the TEVATRON colliders.

In Figs. 9 and 10 we compared the modified DPMJET-III as described in this paper also with the p-p preliminary data of the BRAHMS-Collaboration[25] on charged hadron transverse momentum distributions at pseudorapidities of 0, 1, 2.2 and 3.2.

Using DPMJET-III with modified transverse momentum distributions in hadronic soft chain decay in Figs.11 and 12 we find like in d-Au collisions an improved agreement between DPMJET-III and the preliminary data on π^+ , π^- , K^+ , K^- , proton and antiproton transverse momentum distributions in p-p collisions from the STAR-Collaboration[20].

Transverse momentum distributions of neutral strange hadrons in minimum bias p-p collisions were measured by the STAR-Collaboration[26]. In Fig.13 we compare DPMJET-III with modified transverse momentum distributions in hadronic soft chain decay to these preliminary STAR data. The agreement is satisfactory.

7. Summary

The data obtained at RHIC are extremely useful to improve hadron production models like DPMJET-III.

Of particular importance are data on hadron production in p-p collisions, d-Au collisions and peripheral Au-Au collisions, in all of these collisions (unlike central Au-Au collisions) we do not expect any change in the reaction mechanism, which might not be accommodated into the mechanisms as implemented in DPMJET-III.

Indeed, comparing DPMJET-III to RHIC data we find three important corrections to be applied to DPMJET-III, which otherwise do not completely change the independent chain fragmentation model: (i) Percolation and fusion of chains, the data from RHIC allow to determine the amount of percolation to be implemented into DPMJET-III. (ii) Collision scaling of large p_\perp hadron production in d-Au collisions: The data indicate that we have to change the iteration procedure (of the selection of all soft and hard chains in nuclear collisions) in such a way, that collision scaling is obtained. (iii) Replacing in soft hadronic collisions the Gaussian transverse momentum distribution contained in the JETSET-PYTHIA code [21] by an exponential distribution.

REFERENCES

1. A. Capella, U. Sukhatme, C. I. Tan, and J. Tran Thanh Van, Phys. Rep. **236**, 227 (1994).
2. F.W.Bopp, J.Ranft, R.Engel and S.Roesler, hep-ph/0403084 (unpublished).
3. S. Roesler, R. Engel, and J. Ranft, Proceedings of ICRC 2001, Copernicus Ges. , (2001).
4. S. Roesler, R. Engel, and J. Ranft, hep-ph/0012252, Proc. of Monte Carlo 2000, Lisboa, Oct.2000, Springer,p.1033 , 1033 (2000).
5. R. Engel, Z. Phys. **C66**, 203 (1995).
6. R. Engel and J. Ranft, Phys. Rev. **D54**, 4244 (1996).
7. S.S.Adler et al, PHENIX Collaboration, hep-ex/0304038 (unpublished).
8. J. Dias de Deus and R. Ugoccioni, Phys. Lett. **B491**, 253 (2000).
9. J. Dias de Deus and R. Ugoccioni, Phys. Lett.

- B494**, 53 (2000).
10. J. Dias de Deus, Y. M. Shabelski, and R. Ugoccioni, hep-ph/0108253 (unpublished).
 11. M. Braun, F. del Moral, and C. Pajares, Phys. Rev. **C65**, 024907 (2002).
 12. M. A. Braun, C. Pajares, and J. Ranft, Int. J. Mod. Phys. **A 14**, 2689 (1999).
 13. M. Braun and C. Pajares, Eur. Phys. J. **C16**, 359 (2000).
 14. B.B.Back et al, PHOBOS Collaboration, nucl-ex/0311009 (unpublished).
 15. I.Arsene, BRAHMS Collaboration, nucl-ex/0401025 (unpublished).
 16. R.Nouicer et al, PHOBOS Collaboration, nucl-ex/0403033 (unpublished).
 17. R.Nouicer, PHOBOS Collaboration, presened at Quark Matter 2004, Oakland, USA (unpublished).
 18. S.S.Adler et al, PHENIX Collaboration, Phys.Rev.Lett. **91**, 072303 (2003).
 19. F.Matathias, PHENIX Collaboration, presened at Quark Matter 2004, Oakland, USA (unpublished).
 20. J.Adams et al, STAR Collaboration, nucl-ex/0309012 (unpublished).
 21. T. Sjöstrand *et al.*, Comp. Phys. Commun. **135**, 238 (2001).
 22. R.Hagedorn and J.Ranft, Suppl. al Nuovo Cim. **6**, 169 (1968).
 23. J. Ranft, R. Engel, and S. Roesler, hep-ph/0012112, Proc. of Monte Carlo 2000, Lisboa, Oct.2000, Springer, 979 (2000).
 24. G.I.Veress, PHOBOS Collaboration, presened at Quark Matter 2004, Oakland, USA (unpublished).
 25. I.Arsene, BRAHMS Collaboration, nucl-ex/0403005 (unpublished).
 26. J.Adams and M.Heinz, STAR Collaboration, nucl-ex/0403020 (unpublished).

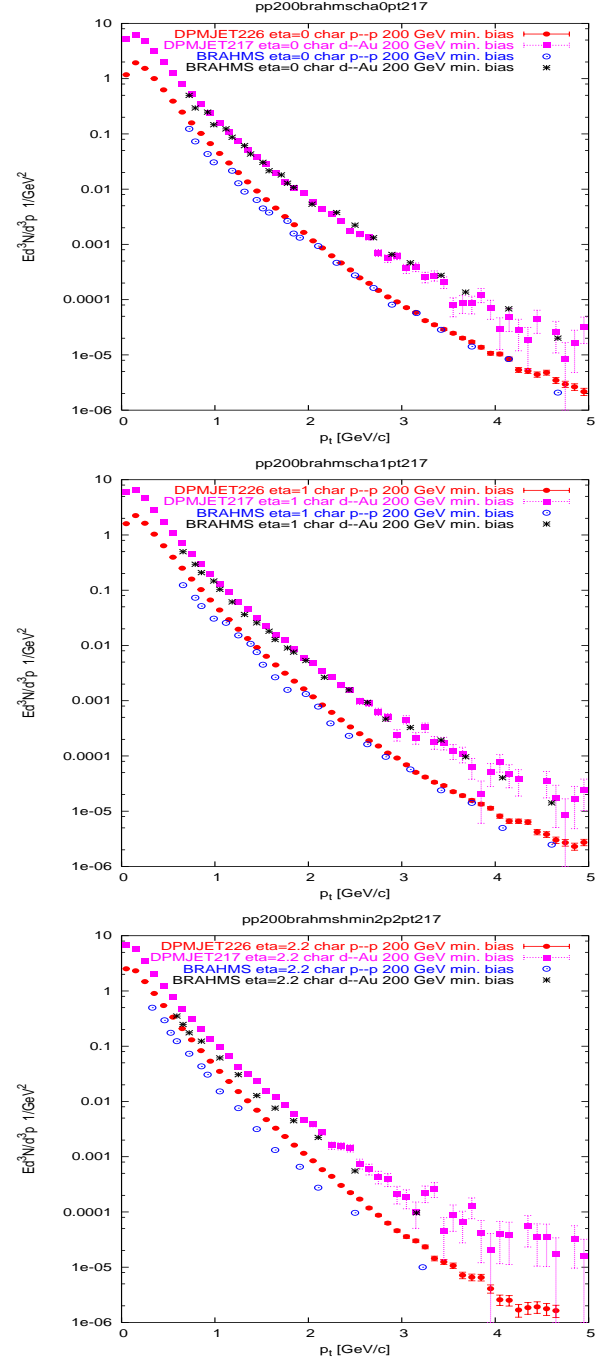


Figure 9. Transverse momentum distributions of all charged hadrons at $\eta_{cm} = 0$, at $\eta_{cm} = 1$, and at $\eta_{cm} = 2.2$ in minimum bias p-p and d-Au collisions. See caption Fig.10

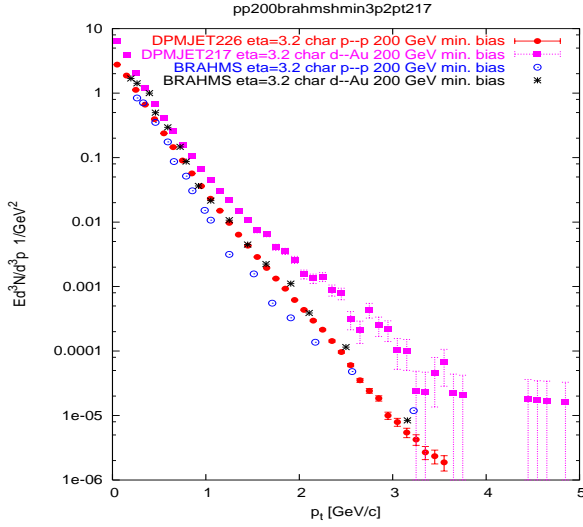


Figure 10. Transverse momentum distributions of all negatively charged hadrons at $\eta_{cm} = 3.2$ in minimum bias p-p and d-Au collisions. Compared are the preliminary data from the BRAHMS-Collaboration[25] to the results of DPMJET-III with modified transverse momentum distribution in hadronic soft chain decay as described in the paper.

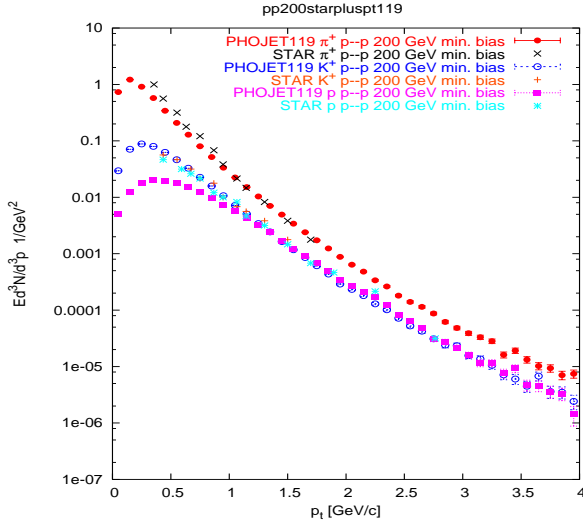


Figure 11. Transverse momentum distributions of positively charged hadrons in minimum bias p-p collisions. Compared are the preliminary data from the STAR-Collaboration[20] to the results of the DPMJET-III with modified transverse momentum distributions in hadronic soft chain decay as described in this paper.

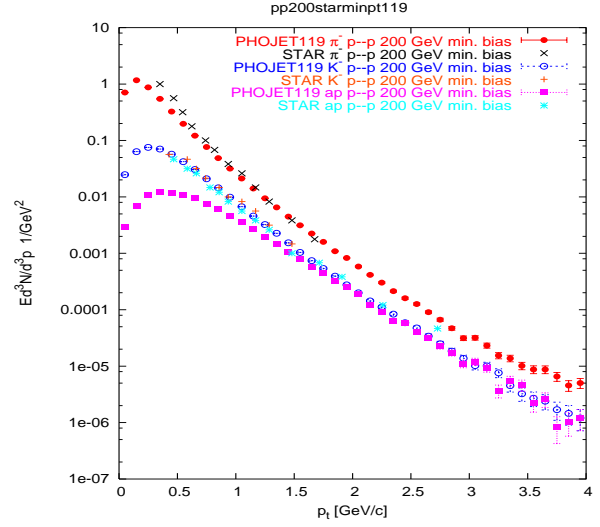


Figure 12. Transverse momentum distributions of negatively charged hadrons in minimum bias p-p collisions. Compared are the preliminary data from the STAR-Collaboration[20] to the results of the DPMJET-III with modified transverse momentum distributions in hadronic soft chain decay as described in this paper.

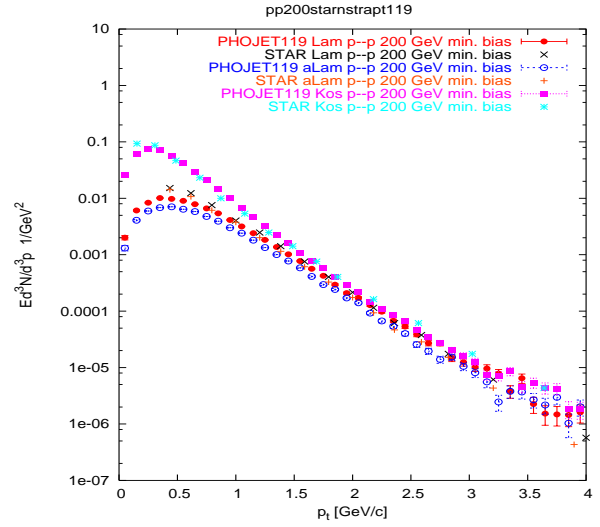


Figure 13. Transverse momentum distributions of neutral strange hadrons in minimum bias p-p collisions. Compared are the preliminary data from the STAR-Collaboration[26] to the results of the DPMJET-III with modified transverse momentum distributions in hadronic soft chain decay as described in this paper.